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Theme 2: Opportunities and Challenges with Operation using Flexibility

Delivering distribution system flexibility through micro-resilience

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Abstract: This study introduces the specific grid challenges faced at each of four micro-resilence sites and provides an overview of the innovative technical solutions deployed to improve grid flexibility, resilience and improve the distribution system operator customer experience. The sites were chosen due to their remote locations and reliance on a reliable electrical service due to dependent customers or lifesaving functions. Therefore, in addition to providing flexible grid services, when grid connected, there is also the opportunity to provide a reliable electrical supply to islanded pockets when there are high-voltage grid outages. The solution architecture and functions of technology such as the two-terminal power electronic devices (PEDs) and microgrid controller (MGC) are described. The combination of an energy storage system, distributed energy resources and PEDs will provide essential grid support functionality with co-ordination of devices, islanded status and data logging handled by a dedicated MGC. Also presented is the application of the Open Field Message Bus, open-standards communications framework for a field message bus, and a description of the specific interoperability use cases demonstrated within the project. This study provides valuable insights into a leading innovation project, delivered on operational networks to address practical customer issues through flexibility.

1 Introduction

Reflecting the nature of the local grid infrastructure, customers in rural or remote areas often experience higher frequency of outage due to the sparser networks and the high cost per customer of conventional 'steel and copper' grids in these areas. Northern Powergrid, Smarter Grid Solutions and Turbo Power Systems are demonstrating innovative microgrid (MG) solutions that will increase resilience for low-voltage (LV) customers whilst offering flexibility to support the wider high-voltage (HV) network. Such flexibility involves distributed energy assets supporting phase balancing, voltage support, power factor correction and islanded operation under planned (*maintenance*) and unplanned (*fault*) outages. These novel solutions are being deployed at four locations on Northern Powergrid's network: a rural community vulnerable to outages, two remote sites providing critical lifeboat services typically in extreme weather conditions, and a national monument with protected status that limits electrical infrastructure installation.

In order to achieve this flexible functionality Northern Powergrid is installing the following technologies:

- distributed MG controllers (MGCs) to coordinate operational MG use cases,
- two-terminal power electronic devices (PEDs) for control of the MG interface; and
- energy storage assets re-deployed from existing sites.

These technologies will be sited in new purpose designed substations or retro-fitted within existing spaces to meet site requirements. Energy storage assets are connected to the DC bus of the power electronics device, providing enhanced control of storage allowing delivery of the MG use cases (islanded operation, grid-to-island transition, island-to-grid transition, interconnected operation). Existing and future distributed energy resources (DERs) will integrate into the MG system providing the enhanced capability for local demand and wider network services. The deployments will see the first UK delivery of the publish/subscribe Open Field Message Bus (OpenFMB) communications framework to facilitate interoperability.

Customers will benefit from enhanced grid resilience and security at critical or vulnerable locations on the electricity network. In addition, evaluations of the benefits of peer-to-peer publish/subscribe communications and distributed control will be conducted. Utilities will establish design, planning and operational policies for flexible and resilient MGs whilst developing best practice in the area.

2 Deployment sites

For all the deployment sites, changes to the existing electrical network are necessary to facilitate micro-resilience functions via the relocated ESS, PED, MGC, switch controls and monitoring equipment. It is preferred that all devices will be sited within a small substation structure purpose-built for LV distribution equipment along with MG management and control equipment.

2.1 Byrness village

Byrness, Fig. 1*a*, is a remote village in Northumberland close to the England–Scotland border consisting of ∼50 houses, a youth hostel and a village hall. It is fed via a long, radial 20 kV feeder. The site experiences challenges due to the remote and vulnerable nature of the electricity supply, with greater than average outages. Under outage conditions, significant works are required to maintain supply, including standby generation which can take up to four hours to transport to the site. There are two LV circuits and both have electrically dependent customers. It will be necessary to

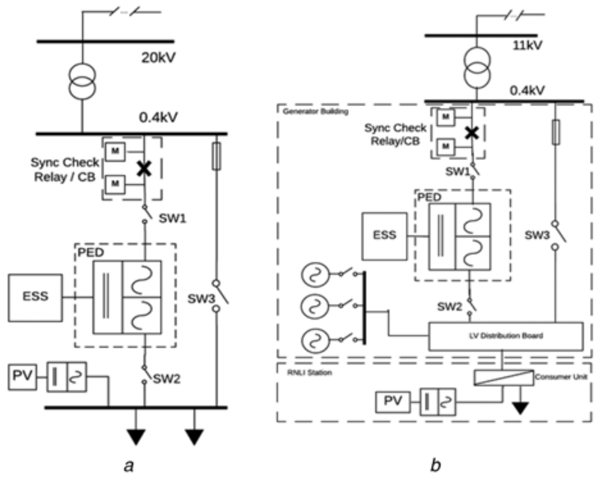

Fig. 1

a Proposed layout at Byrness village
b Proposed layout at Spurn Point

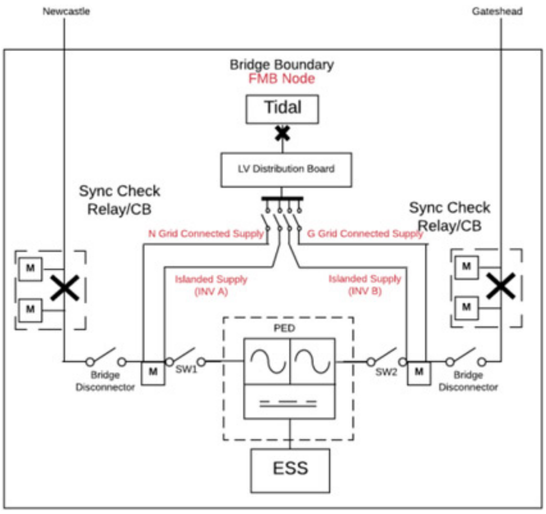

Fig. 2 *Proposed layout at Newcastle Swing bridge*

manage the new energy storage system (ESS) capacity effectively by involving the local community via voluntary demand reduction and introducing smaller forms of DERs.

Resilience will be achieved via the PED with relocated ESS assets coupled to the DC bus. The following flexibility modes of operation, under the grid-connected use case, will be integrated: phase balancing, power factor correction and real power export (point of common coupling, zero net flow to achieve a planned transition to a MG).

2.2 Spurn Point

Spurn Point, Fig. 1*b*, is a site of special scientific interest located at the mouth of the Humber River in East Yorkshire and fed by a long 11 kV feeder that crosses an exposed stretch of sand dunes. The site has three electricity customers: RNLI Humber – the site is manned 24/7, 365 days a year, Associated British Ports (ABP) – the site provides radar communications for the fifth largest port network in Europe and the Yorkshire Wildlife Trust (YWT), which has a visitor centre at Spurn Point.

An electricity supply is critical for RNLI and ABP to maintain operations at Spurn Point. The site is supplied by both overhead line and underground cable network that is susceptible to damage, being exposed or outages as the sand dune environment it runs through shifts due to natural forces. Network outages are common on the site, with an anecdotal typical duration of several hours, which can be several days for more serious outages.

The site has three backup diesel generators that provide supply during grid outage conditions, although refuelling them requires moving diesel through this remote site of special scientific interest. The challenge is to provide a level of resilience for Spurn Point when the feeder is out of service and ensure supplies to the critical services are without reliance on expensive and polluting back up generation.

Resilience and flexibility services will be achieved with the deployment of ESS, PV and a PED to offer voltage support and facilitate islanded operation.

2.3 RNLI Sunderland

RNLI Sunderland is a lifeboat station located in Sunderland Marina. The site provides critical lifeboat emergency service, typically in extreme weather conditions. The site is raised above the marina and consists of a dry lifeboat dock that houses a Rigid Inflatable Boat (RIB), an office and a training centre. During an event, an electric motor raises the station security shutters, the RIB is moved towards the marina on tracks, and a motorised launch crane is used to lower the lifeboat 25 feet into the marina waters. Under outage conditions, the site has a small battery backup to maintain supply to communications equipment. The shutters and launch crane must be operated manually under outage conditions, which can significantly delay lifeboat launch and may put lives at risk.

Resilience is proposed through the deployment of an ESS device. In addition, an OpenFMB node will be set up with remote links to Newcastle Swing Bridge. The purpose of which is to exchange information (e.g. weather) such that islanding decisions can be made (e.g. charge ESS, move to islanded mode).

2.4 Newcastle Swing Bridge

Newcastle Swing Bridge, Fig. 2, is a Grade II listed historic monument crossing the River Tyne linking the cities of Newcastle and Gateshead. The bridge was constructed in 1876, with electric supply introduced in 1930. Its mechanism is driven by hydraulic pumps, which in turn are supplied by electric water pumps, fed from the local LV network. The incoming LV supply is in a poor condition and will require reinstatement in the near future. Northern Powergrid anticipates difficulty and significant cost in reinstating the LV supply via the existing route.

When the supply to the swing bridge is lost, a temporary solution introduces a standby generator.

Grid flexibility and resilience are proposed with the deployment of LV switching, PED, ESS and potentially a tidal generator. The new LV supplies will emanate from Gateshead and Newcastle and will provide an electrical bridge, a Soft Open Point (SOP) [1], between the LV networks enabling the transfer of power in addition to voltage support and phase balancing. The bridge will also form a remote OpenFMB node for information exchange with RNLI Sunderland.

3 MG design

3.1 Architecture

An overview of the proposed architecture is shown in Fig. 3. The local decision making capability and criteria will be delivered through the deployment of the OpenFMB framework and the MGC.

3.2 Remote field bus communications

A requirement is to demonstrate communication between two OpenFMB nodes at Newcastle and Sunderland. Communication between the two sites will be achieved using a 3G/4G based wireless network. The middleware must be capable of exchanging OpenFMB messages between two remote modes.

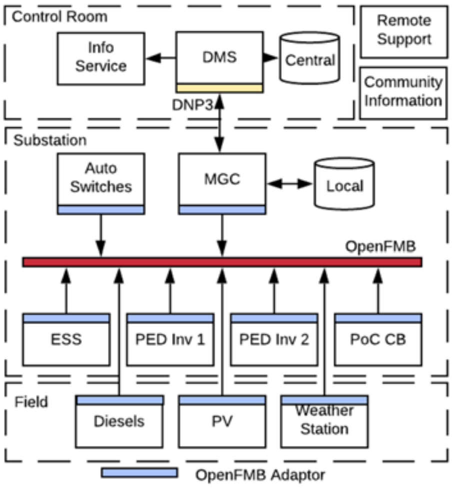

Fig. 3 *High-level architecture*

3.3 *Middleware options*

The TCP/IP protocols are the best suited to wide-area network communication therefore messaging standards that natively support TCP/IP are preferred. MQTT in particular was designed for unreliable wireless networks. MQTT is the simplest standard and there are several mature free client/broker open-source implementations [2].

3.4 *OpenFMB use cases*

There are existing OpenFMB Use cases [3] that have been previously demonstrated. Those use cases where appropriate shall be deployed to ensure that planned and unplanned transitions to a MG can be made and vice versa, whilst operating in a grid-connected and islanded mode are also both possible. Where an existing use case does not cover the precise operational needs of the sites or existing device profiles cannot be overlaid directly contributions will be made to the OpenFMB community.

3.5 *MG controller*

The MGC, Fig. 4, will be embedded at each MG location and will provide local access to the system via a user interface and inform the control centre of islanded status and other operational metrics as required. The platform will comprise an ANM Strata, SGS' standard DERMS product, deployed on a ruggedised substation computing platform. The component parts, communication gateway, logic engine and application host, allow for the implementation of MG logic, measurements, status and control of the MG area and the individual devices. The powerful logic engine can be updated with new devices, the removal of devices and enhance functionality as requirements evolve in future use cases.

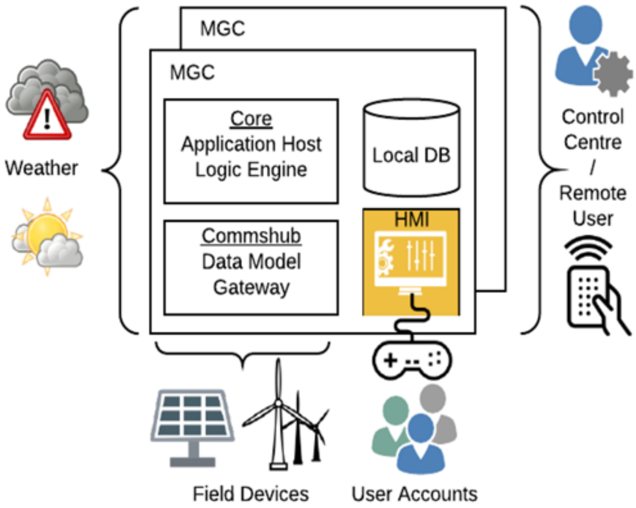

Fig. 4 *MG controller*

The MGC enables the MG logic to be applied across the islanded area in addition to providing the necessary modes for offering grid support services. The logic will be MG specific to ensure individual devices are operating in the correct mode to meet island/grid commands and marshal state transitions to ensure compliance. It will provide communications to the control centre and to other local MGCs subscribing to data pertinent to the correct operation of its local devices and publishing data relevant to the other MGCs. Thus, the MGC can have holistic visibility of its local area and provide that information for wider area control functions.

The flexibility of the platform allows the interconnection of MGCs, the ability to manage MG constraints and use resources to manage wider network constraints to which each islanded pocket makes a contribution. This opens the opportunity to optimise feeder variables to ensure efficient and secure delivery of energy to its customers.

3.6 *Power electronics device*

The PED is a product development derived from the SOP concept [1] and the extensive experience in grid linked converter manufacture. The solutions are based on the multi-terminal PED. Each multi-terminal PED consists of multiple power electronic stacks, which are connected internally by a common DC link. As the power electronic stacks are capable of bi-directional power transfer by acting as either an active three-phase rectifier to the DC link (power import) or as a three-phase inverter to the LV network (power export), it is possible to transfer power between terminals and therefore between LV network substations or other nodes. Using an advanced control algorithm, both current and voltage can be manipulated in the individual phases that allow the PED to perform the functions of reactive power support, voltage support, power factor correction, phase imbalance improvement, loss reduction, harmonic content improvement and black start.

External connectivity to the DC Bus between the electronic stacks, either directly or via suitable DC–DC matching schemes, gives additional flexibility for introducing ESSs and DC distribution networks.

The PED system will act as a gateway and interface between the incoming feeder and the low-voltage network. Having access to both sides of the network, the PED can control the energy flow and provide network support functions. The PED DC link will have a bi-directional DC–DC capability for energy storage management. The control mechanisms to achieve this are based on carefully constructed algorithms that will centre on vector transformations of the measured three-phase voltages and currents at both terminals to provide a robust control structure. The vector transformation is similar to the familiar d–q transformation used in modelling rotating machines and it converts a three-phase set of positive sequence voltages into a dc quantity. Negative sequence components are converted to a double frequency component that can be removed from the control signal using digital filtering techniques. The control strategy employed by the PED during single- and two-phase faults are designed to keep the PED online so that it will support the system voltage when the fault is cleared. During this period, the PED will attempt to inject current to support bus voltage at the faulted terminal. Instantaneous current limiting, achieved by turning off the IGBT's whenever a line current exceeds a set value, is used to maintain current control.

4 Conclusions

From the communications perspective, it has been identified that MQTT offers advantages and therefore this middleware option will be used in all stages of this project. The field bus will comprise individual data and control buses.

Policy and procedures are needed to be addressed to ensure the safety of personnel and the installation, commissioning and operation of MGs. Extensive pre-deployment testing will be conducted at the Power Networks Demonstration Centre (PNDC).

PED design changes have been made to use high-power silicon carbide (SiC) semiconductor modules as SiC has low conduction losses and can switch at high frequencies thus having better efficiency and lower acoustic operation. The expected outcome is a highly efficient (>98%), low noise and small physical footprint converter system. Generally, there are higher percentage losses at the LV transformers than in the HV/EHV networks.

The deployment of higher efficiency devices, compared to existing distribution transformers, can offer benefits with the advancement of controls in addition to those on traditional distribution transformers. There is a significant opportunity to deliver resilience and flexibility through the deployment of communicating MGs utilising devices capable of implementing controls on the LV networks to reduce losses.

5 References

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